

GENERATION OF RECONSTRUCTED IMAGE DATA BASED ON MOVED DISTANCE AND TILT OF SLICE DATA

BACKGROUND OF THE INVENTION

5 1. Field of the Invention:

The present invention relates to an image processing apparatus, an image processing method, and a program.

2. Description of the Related Art:

With the widespread use of information processing devices in recent 10 years, it has been more customary than ever before for people to carry small-size information terminals that store highly confidential information. Using biological characteristics of the user of an information terminal as an authentication technique to protect such confidential information is one of the best approaches to prevent others from "impersonating" the user. Of various 15 biological authentication techniques, fingerprint authentication in particular is promising in that it allows information terminals to be easily reduced in size, the cost required to construct fingerprint authentication devices is relatively low, and fingerprints differ from person to person and do not change with time.

20 Many devices for reading fingerprints traditionally comprise a two-dimensional sensor, i.e., a planar sensor (see Fig. 1A of the accompanying drawings). However, the recent tendency toward small-size information terminals has drawn much attention to a one-dimensional sensor, i.e., a line sensor (see Fig. 1B of the accompanying drawing).

25 The line sensor is a device that has been developed for the purposes of achieving smaller sizes and low prices. A fingerprint reading sensor as an

example of line sensor is a device for generating image data of a fingerprint from a number of sectional image (slice) data that are successively acquired when a finger is moved across the fingerprint reading sensor (such an action is hereinafter referred to as "sweeping").

5 One conventional line sensor that has been proposed as a fingerprint reading sensor is a fingerprint identifying device having a frame input unit, an optimum position calculator, a template image memory, a partial synthetic image memory, an image synthesizer, a checking feature extractor, a template checking feature memory, and a fingerprint feature checking unit (see,
10 for example, JP-A- 2002-42136). For reconstructing an overall image from a series of partial images entered from the frame entering unit, the optimum position calculator checks a partial image against a fingerprint image (template image) of the user that is stored in the template image memory to determine a position where the similarity is the highest, and the image synthesizer joins the partial image to a partial synthetic image that is stored in the partial synthetic image memory. The above process is carried out for each
15 of partial images that are produced, thus generating a synthesized image. Then, the checking feature extractor extracts features from the synthesized image, and the fingerprint feature checking unit checks the extracted features against features in the template image that are stored in the template checking feature memory. The fingerprint identifying device is capable of confirming the user quickly and accurately using a group of partial images of the fingerprint that are produced by the relative movement between a sensor having a small area and the finger.

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25 However, when fingerprint images are generated with the conventional line sensor, the user is likely to sweep the finger differently across the

line sensor for various reasons. For example, the user may move the finger in a direction that is opposite to the direction which the user is expected to follow in sweeping the finger across line sensor (see Fig. 2A of the accompanying drawings), or the user may sweep the finger along a curved path 5 across the line sensor because of the way the line sensor is installed or the motion of finger joints (see Fig. 2B of the accompanying drawings). If the finger does not sweep the line sensor as expected, then it is difficult for the line sensor to produce accurate fingerprint images.

The above problem occurs with not only fingerprint reading sensors, 10 but also other line sensors such as sensors for use in scanners.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an image processing apparatus, an image processing method, and a program which 15 are capable of generating distortion-free accurate image data.

According to the present invention, an image processing apparatus comprises an image entering means for reading slice data, an image processing means for being supplied with slice data read by the image entering means and processing the supplied slice data into reconstructed image data, 20 and a memory means for storing data. The memory means comprises a slice data storage means for storing slice data supplied to the image processing means, and a reconstructed image data storage means for storing reconstructed image data produced by the image processing means. The image processing means comprises a significance detecting means for determining whether the slice data stored in the slice data storage means is of 25 significance or not, a moved distance/tilt calculating means for calculating a

5 moved distance and tilt of the slice data that has been detected as being of significance by the significance detecting means, and reconstructed image data generating means for calculating positional coordinates of a reconstructed image area to which the slice data is to be projected, based on the

10 5 moved distance and tilt of the slice data which has been calculated by the moved distance/tilt calculating means, and generating reconstructed image data.

15 A moved distance and tilt of the slice data that has been supplied from the image entering means are calculated, and positional coordinates of a reconstructed image area to which the slice data is to be projected are calculated based on the moved distance and tilt of the slice data which has been calculated by the moved distance/tilt calculating means, thus generating reconstructed image data. Therefore, the orientation of an object is detected, and image data can be reconstructed regardless of whether the

20 15 sweep is normal or inverted. Furthermore, moved distance differences between the slice data and preceding slice data can be detected at a plurality of locations on the slice data, and image data can be reconstructed in a manner to follow a sweep (curved sweep) that is a combination of translation and turning movement. Therefore, it is possible to acquire image data which is substantially free of distortions. Accordingly, the image processing apparatus may, for example, be used in an application in which it is incorporated in a small-size information device for capturing a fingerprint while the user is holding the small-size information device with one hand. The image processing apparatus can be installed in a wide range of locations, has an increased value in its use, and finds a wide range of applications. Moreover,

25 20 no hardware mechanism dedicated to the detection of a moved distance is

required. As a result, the apparatus is simplified in structure and made up of a reduced number of parts, and hence can be manufactured in a reduced period of time at a reduced cost.

The image processing means may start processing the slice data if

- 5 the slice data is determined to be of significance by the significance detecting means, and end processing the slice data if the slice data is determined to be of no significance by the significance detecting means.

The moved distance/tilt calculating means may calculate an overall moved distance and tilt of the slice data by determining relative positions of a

- 10 plurality of moved distance detecting windows provided for the slice data.

The reconstructed image data generating means may divide each pixel of the slice data into fragments at a ratio of occupied areas with respect to a maximum of four pixels of the reconstructed image area onto which each pixel of the slice data is to be projected, and distribute the divided

- 15 fragments to the pixels of the reconstructed image area, thereby generating the reconstructed image data.

The image entering means may comprise a fingerprint reading sensor, a sensor for use with a hand scanner, or a line sensor.

The above and other objects, features, and advantages of the present

- 20 invention will become apparent from the following description with reference to the accompanying drawings which illustrate examples of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

- 25 Fig. 1A is a plan view of a planar sensor;
- Fig. 1B is a plan view of a line sensor;

Figs. 2A and 2B are plan views illustrative of a problem of a conventional line sensor;

Fig. 3 is a block diagram of an image processing apparatus according to a first embodiment of the present invention;

5 Fig. 4 is a flowchart of an operation sequence of the image processing apparatus according to the first embodiment;

Figs. 5A through 5D are diagrams illustrative of a process of calculating a moved distance and tilt of slice data;

10 Fig. 6 is a diagram illustrative of positional coordinates (absolute coordinates) of a reconstructed image area;

Fig. 7 is a diagram illustrative of a process of mapping slice data to the reconstructed image area;

Figs. 8A through 8D are diagrams illustrative of the manner in which a fingerprint image is divided, rotated, and shifted;

15 Fig. 9A is a diagram showing a fingerprint image generated according to the present invention;

Fig. 9B is a diagram showing a fingerprint image generated according to a conventional process; and

20 Fig. 10 is a block diagram of an image processing apparatus according to a fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

1st Embodiment:

As shown in Fig. 3, an image processing apparatus according to a 25 first embodiment of the present invention comprises line sensor (image entering unit) 1, image processor 2 for being supplied with slice data that has

been read by line sensor 1 and processing the supplied slice data, and memory 3.

Line sensor 1 comprises a one-dimensional scanner sensor capable of simultaneously capturing several lines of image data. Line sensor 1 has 5 such characteristics and a shape that match an object whose image data are to be acquired. Line sensor 1 may be an optical, thermosensitive, a pressure-sensitive, or a charge capacitance (CMOS) sensor. Line sensor 1 should have as many pixels as required to meet a requirement for covering a minimum number of overlapping lines between successive slices in order to 10 reconstruct a finger image, and should also have an operating speed large enough to respond to a sweeping action across line sensor 1. Alternatively, a conventional planar sensor may be used instead of line sensor 1. Though the image processing apparatus will be described in detail below with line sensor 1 used to read fingerprint image data, the image processing apparatus 15 is not limited to such a fingerprint imaging application.

Memory 3 comprises a RAM and includes first and second slice buffers 4, 5 (slide data memory) for storing slice data supplied to image processor 2, and reconstructed image data memory 6 for storing reconstructed image data that has been processed by image processor 2.

20 Image processor 2 comprises a processor for processing image data. Image processor 2 has data capturing unit 7 for entering slice data read by line sensor 1 into first slice buffer 4 and second slice buffer 5, significance detector 8 for determining whether the slice data stored in first slice buffer 4 and second slice buffer 5 are of significance or not (i.e., contain a fingerprint 25 or not), moved distance/tilt calculator 9 for calculating a moved distance and tilt of the slice data that has been detected as being of significance by sig-

nificance detector 8, and reconstructed image data generator 10 for calculating positional coordinates of a reconstructed image area to which the slice data is to be projected, based on the moved distance and tilt of the slice data which have been calculated by moved distance/tilt calculator 9, and generating reconstructed image data.

5 Fig. 4 shows an operation sequence of the image processing apparatus according to the first embodiment.

After a fingerprint image starts being captured in step 101, data capturing unit 7 reads slice data from line sensor 1 and stores the slice data in 10 first slice buffer 4 in step 102.

In step 103, significance detector 8 determines whether the slice data stored in first slice buffer 4 is of significance or not. If the slide data is not of significance, then control goes back to step 102 to read slice data from line sensor 1.

15 If the slide data is of significance in step 103, then it is judged that a finger has started sweeping line sensor 1. Significance detector 8 stores the slice data in first slice buffer 4 in a start position of a reconstructed image area in step 104.

20 Data significance is checked based on the fact that slice data that is read from line sensor 1 when the finger contacts line sensor 1 largely changes positively or negatively from preceding slice data. The manner in which the slice data changes depends on the characteristics of line sensor 1 used, the detector needs be corrected depends on the type of line sensor 1. According to the present embodiment, the slice data is judged as being of 25 significance when at least a certain number of pixels detect being contacted by the finger.

Actually, line sensor 1 comprises a temperature sensor or an electrostatic capacitance sensor. Line sensor 1 provides a temperature difference or an electrostatic capacitance change as 16- or 256-level data per pixel.

Significance detector 8 acquires the data output from line sensor 1 at given 5 time intervals, and judges that the object, i.e., the finger, on line sensor 1 has moved if there is a large change between the output data at time t and the output data at time t+1 in the same pixel position.

In step 105, data capturing unit 7 reads next slice data from line sensor 1 and stores the slice data in second slice buffer 5. In step 106, significance 10 detector 8 determines whether the slice data stored in second slice buffer 5 is of significance or not. If the slice data is not of significance, then significance detector 8 judges that the sweep is ended, and the acquisition of the fingerprint image is put to an end in step 113.

If the slice data is of significance in step 106, then moved distance/tilt 15 calculator 9 compares the slice data stored in first slice buffer 4 and the slice data stored in second slice buffer 5 with each other and calculates a moved distance and tilt of the slice data in step 107.

Figs. 5A through 5D are illustrative of a process of calculating a moved distance and tilt of slice data. As shown in Fig. 5A, a moved distance 20 and tilt of slice data are calculated using two moved distance detecting windows 11a, 11b that are provided for the respective slice data. Specifically, one of the windows is fixed in position and the other window is moved vertically and horizontally to find windows having substantially the same data patterns. When the difference between the relative positions of the two windows 25 is zero, the moved distance of the slice data is zero.

The relative positions of the two windows can change from an inverted sweep direction (negative) to a normal sweep direction (positive) and also in horizontal directions. Since the speed at which the finger sweeps does not change abruptly, an area for calculating the relative positions is narrowed down based on the preceding moved distance. Because the negative direction is supported, an image can be reconstructed accurately even when the finger sweeps across the sensor inversely or reciprocally. Even when the finger stops (the moved distance becomes zero) while sweeping across the sensor, an image can be reconstructed accurately.

When the respective relative positions of two windows 11a, 11b are determined, a moved distance (dx, dy) and tilt ($d\theta$) of the slice are calculated from the determined relative positions (see Fig. 5B). Specifically, coordinates of an upper left end of the slice (relative coordinates with respect to the preceding slice) are calculated based on dx, dy that have been calculated for each of the windows. If there are two windows, then providing moved distance differences with respect to individual windows 11a, 11b are represented by $(dx_1, dy_1), (dx_2, dy_2)$, as shown in Fig. 5C. Since dx_1, dx_2 are of substantially the same values because of the structure of the sensor, their representative value is determined by averaging them. Thus,

$$dx = (dx_1 + dx_2)/2 \quad (1)$$

Inasmuch as the difference between dy_1, dy_2 serves as a parameter that determines the tilt between the slices, dy at the upper left end and $d\theta$ are determined using the ratio of the distances from the left end to the respective windows. Specifically, if the distance between dy_1 and dy is indicated by a and the distance between dy_2 and dy by b as shown in Fig. 5D, then

$$(dy1 - dy)/a = (dy2 - dy)/b$$

and hence,

$$dy = a \times dy2/(a - b) - b \times dy1/(a - b)$$

$$dy = R1 \times dy1 - dy2 \quad (2)$$

5 where $R1$ is of an inherent value depending on the positions of the windows, and varies depending on the ratio of a and b .

Furthermore,

$$\tan\theta = (dy2 - dy1)/(b - a)$$

and hence,

$$10 \quad d\theta = \tan((dy2 - dy1) \times R2) \quad (3)$$

where $R2$ is of an inherent value depending on the positions of the windows, and varies depending on the ratio of a and b .

In step 108, reconstructed image data generator 10 calculates positional coordinates (absolute coordinates) of a reconstructed image area
15 where data is to be stored next, from the position of the preceding slice stored in the reconstructed image area and the moved distance and tilt which have been detected by moved distance/tilt calculator 9, and stores (maps) the slice in second slice buffer 5 in the reconstructed image area.

The absolute coordinates are calculated using dx , dy , $d\theta$ according to
20 the following equations (see Fig. 6):

$$x = \sum(dx \times \cos\theta - dy \times \sin\theta) \quad (4)$$

$$y = \sum(dx \times \sin\theta + dy \times \cos\theta) \quad (5)$$

$$\theta = \sum d\theta \quad (6)$$

The above equations serve to calculate actual coordinates, and ac-
25 cumulate relative coordinates that have been calculated each time slice data is acquired, thereby determining relative coordinates from the time when the

sweep started, i.e., absolute coordinates if the time when the sweep started is set to 0. x, y, θ at the time n slice data are acquired represent the sums of $dx, dy, d\theta$ that have been derived from the 1st slice to the n th slice. If $dx(i), dy(i), d\theta(i)$ indicate a moved distance and tilt between the i th slice data and 5 the $(i+1)$ th slice data determined according to the equations (4) through (6), then the following equations are satisfied:

$$x(i) = \sum_{i=1}^{n-1} (dx(i) \cos \theta(i) - dy(i) \sin \theta(i)) \quad (7)$$

$$y(i) = \sum_{i=1}^{n-1} (dx(i) \sin \theta(i) + dy(i) \cos \theta(i)) \quad (8)$$

$$\theta(i) = \sum_{i=1}^{n-1} d\theta(i) \quad (9)$$

10 Using the coordinates (x, y) and the angle θ thus calculated, the slice data is projected (mapped) onto reconstructed image data.

15 If the moved distance has a value that is not exactly divisible by the length of a pixel or the angle $d\theta$ has a value other than zero, then a slice to be stored is not in 1-to-1 correspondence to pixels in the reconstructed image area. Specifically, a pixel of the slice is distributed and projected onto a maximum of four pixels of the reconstructed image area at the time of mapping (see Fig. 7).

20 If coordinates are determined simply in agreement with the pixel pitch, then continuity at the boundaries is lost, making it impossible to reconstruct a good fingerprint image. To solve this problem, reconstructed image data generator 10 performs a smoothing process in step 109 by dividing each pixel of the slice into fragments at a ratio of occupied areas with respect to a maximum of four pixels of the reconstructed image area onto which each pixel of the slice is to be projected, and distributing the divided fragments to

the pixels of the reconstructed image area. Specifically, coordinates to be projected and a projection value for a pixel having coordinates (sx, sy) on the slice data and three pixels that are positioned rightward, downward, and rightward and downward of the pixel are calculated.

5 When the coordinates of the upper left end of an *i*th slice are indicated by $x(i)$, $y(i)$, the slice data is inclined at $\theta(i)$ from those coordinates, the projected coordinates of a pixel on the slice data are expressed by:

$$(x + sx \times \cos\theta - sy \times \sin\theta, y + sx \times \sin\theta + sy \times \cos\theta)$$

(10)

10 The projection value is expressed by:

$$\begin{aligned} & \text{difx} \times \text{dify} \times s(sx, sy) + \\ & \text{difx} \times (1 - \text{dify}) \times s(sx, sy + 1) + \\ & (1 - \text{difx}) \times \text{dify} \times s(sx + 1, sy) + \\ & (1 - \text{difx}) \times (1 - \text{dify}) \times s(sx + 1, sy + 1) \end{aligned}$$

15 (11)

where (x, y) represent the absolute coordinates of a slice which have been calculated previously, difx, dify the differences (a value from 0 to 1) between the absolute coordinates and slice coordinates, and $s(x, y)$ the value of a pixel on the slice.

20 Actually, one pixel has such a feature that when it is converted to a coordinate value, it has a size of 64 times, for example (if a certain pixel is of coordinates $(0, 0)$, then a right pixel next thereto has coordinates $(64, 0)$). By thus determining coordinates with higher accuracy than pixels, it is possible to handle intermediate positions and tilts. Equation (11) serves to project
25 coordinate values onto actual pixel units.

Projected pixels surrounded by a region of four adjacent pixels ($S(s_x, s_y) - S(s_x+1, s_y+1)$) on slice data are calculated according a ratio of occupied areas of the four pixel data. The occupied areas are expressed by the variables df_x, df_y in equation (11).

5 The moved slice is stored in the reconstructed image area of reconstructed image data memory 6.

Then, in step 110, reconstructed image data generator 10 determines whether the moved slice can be stored in the reconstructed image area or not. If the moved slice can be stored in the reconstructed image area, then
10 the slice in second slice buffer 5 is shifted to first slice buffer 4 in step 111, and then a next slice is read. If the reconstructed image area is full and cannot store more slice data, then a next slice is not read, and the acquisition of the fingerprint image is put to an end in step 113.

Rather than shifting the slice in second slice buffer 5 to first slice
15 buffer 4, the two buffers may alternately be used to carry out the same process as described above.

The coordinates in the reconstructed image area are endless because of wraparound. Specifically, when the absolute coordinates of a new slice overflow an end of the reconstructed image area, they are stored in the other
20 end of the reconstructed image area, so that the slice data will not be lost. However, since the slice data thus stored would not constitute a single continuous fingerprint image, after the acquisition of a fingerprint image is put to an end, a true starting point of the fingerprint image in the reconstructed image area is determined (see Fig. 8A), the image is vertically divided about
25 the starting point (see Fig. 8B), then turned 180° (see Fig. 8C), and shifted

horizontally (see Fig. 8D), thus producing a proper fingerprint image in step 112.

If a sufficient working area is available for an image to be generated, then the processing of step 112 may be dispensed with by setting the center 5 of the working area to coordinates (0, 0).

The fingerprint image thus reconstructed is shown in Fig. 9A. As a comparative example, Fig. 9B shows an image acquired as a sweep image by a conventional process which is incapable of handling rotation. In Figs. 9A and 9B, the images are produced when the finger sweeps the line sensor 10 while being intentionally turned counterclockwise. It can be seen that the fingerprint image shown in Fig. 9A is essentially free of distortions.

According to the first embodiment, a moved distance and tilt of slice data acquired from line sensor 1 are calculated, and positional coordinates of a reconstructed image area to which the slice data is to be projected are calculated based on the calculated moved distance and tilt of the slice data, 15 thereby generating reconstructed image data. Therefore, the orientation of the sweep is detected, and the image data can be reconstructed regardless of whether the sweep is normal or inverse. Furthermore, moved distance differences between the slice data and preceding slice data can be detected 20 at a plurality of locations on the slice data, and image data can be reconstructed in a manner to follow a sweep (curved sweep) that is a combination of translation and turning movement. Even when the movement of the finger is curved or tortuous with respect to line sensor 1, or the finger sweeps line sensor 1 in an inverse direction, it is possible according to the present embodiment 25 to reconstruct a fingerprint image that is equivalent to a fingerprint image which would be produced if the finger sweeps line sensor 1 in the

normal direction. Accordingly, the image processing apparatus can be installed in a place where distorted fingerprint images would heretofore be captured, for capturing fingerprint images that are equivalent to those acquired by planar sensors and in other installed locations. As a result, the image processing apparatus may, for example, be used in an application in which it is incorporated in a small-size information device for capturing a fingerprint while the user is holding the small-size information device with one hand. The image processing apparatus can be installed in a wide range of locations, has an increased value in its use, and finds a wide range of applications.

2nd Embodiment:

According to the first embodiment, the image processing apparatus has two slice buffers. However, the image processing apparatus may have a single slice buffer having a sufficient capacity required for a single sweep.

The image processing apparatus with the single slice buffer needs a large buffer area, but is advantageous when line sensor 1 is slow in speed or the processor has an insufficient processing capability. This is because the single slice buffer can read slices successively and subsequently carry out an image reconstruction process altogether, so that more overlaps of the slices can be obtained than with the first embodiment. The more the overlaps of the slices, the better the reconstructed image data.

3rd Embodiment:

According to the first embodiment, the image processing apparatus has two moved distance detecting windows. However, the image processing apparatus may have three or more moved distance detecting windows. With the three or more moved distance detecting windows, it is possible to accu-

rately generate an image even if the finger sweeps the sensor while in contact with about one-half of the area of the sensor.

If there are N moved distance detecting windows, then since the number of windows is increased in order to increase the accuracy with which

5 to detect a moved distance and tilt, the accuracy of individual windows is checked and then a moved distance is detected from an optimum point. Specifically, dx values of individual windows are compared, and their average is determined after eliminating any data that are greatly different from other data. Then, dy and $d\theta$ are determined between the remaining windows.

10 For example, if three windows have remained, three dy and $d\theta$, and if four windows have remained, six dy and $d\theta$, are produced according to equations (2), (3). Therefore, these values are averaged into dx , dy , $d\theta$. $R1$, $R2$ in equations (2), (3) change from window to window as they depend on the position of the window.

15 4th Embodiment:

By recognizing the direction of a sweep, it is possible not to reconstruct an image when the finger sweeps the line sensor in a direction which is opposite to the direction in which the finger has started sweeping the line sensor. According to this process, even if line sensor 1 is a directional line

20 sensor (a sensor which outputs an image of different characteristics when swept in a direction inverse to the normal direction), an image can properly be generated. With this arrangement, when the finger sweeps the line sensor in the inverse direction, only coordinates are converted, and no data is projected onto a storage area.

25 5th Embodiment:

Fig. 10 shows in block form an image processing apparatus according to a fifth embodiment of the present invention. According to the fifth embodiment, an image processing program for enabling computer 4 to carry out the operation sequence of image processor 2 described above according to the first through fourth embodiments is stored in storage medium 5, and the CPU of computer 4 reads the image processing program from storage medium 5. Storage medium 5 may comprise a magnetic disk such as an FD or the like, an optical disk such as a CD-ROM or the like, or a recording medium such as a semiconductor memory or the like. The image processing program may be downloaded via a communication network, rather than being stored in storage medium 5.

The present invention is not limited to the above embodiments, but various changes and modifications may be made therein without departing from the technical scope of the invention as defined in claims.

For example, the present invention is concerned with an algorithm for generating an original image from a succession of slice images, and is applicable to anything insofar as it serves the purpose of reconstructing an image with the same arrangement. For example, the present invention is applicable to a hand scanner or the like. Existing hand scanners have a mechanism for detecting a moving speed, e.g., a roller or a sensor, disposed near an image sensor. According to the present invention, such a mechanism may be dispensed with. As a result, the apparatus is simplified in structure and made up of a reduced number of parts, and hence can be manufactured in a reduced period of time at a reduced cost.

The algorithm according to the present invention causes no distortion on a generated image even when an object is scanned along a curved path.

If only the moved distance detector is used, the image processing apparatus according to the present invention may be used as a pointing device having a scrolling function, a cursor moving function, or an alternative mouse function. Specifically, the image processing apparatus according to the present invention may switch between a fingerprint entering device and a scrolling function.

Furthermore, since the present invention makes it possible to detect a tilt, a rotation can be detected by integrating a detected tilt. A device which has no actuator and is capable of entering a tilt and angular displacement may be used in various applications as an alternative to a dial or a volume.

While preferred embodiments of the present invention have been described using specific terms, such description is for illustrative purposes only, and it is to be understood that changes and variations may be made without departing from the spirit or scope of the following claims.